DRAFT The status of Vermilion Rockfish (*Sebastes miniatus*) and Sunset Rockfish (*Sebastes crocotulus*) in U.S. waters off the coast of California north of Pt. Conception in 2021

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Contents

Two fish of the vermilion/sunset cryptic species pair. Confirmation of species can only be determined via genetic analysis and species identification of these two fish caught in the Santa Barbara channel at approximately 250 ft depth is unknown. Photo courtesy of Sabrina Beyer (UCSC/NOAA).

Executive Summary

Stock

This assessment reports the combined status of the vermilion rockfish (*Sebastes miniatus*) and sunset rockfish (*Sebastes crocotulus*), referred to as "vermilion rockfish" throughout, in U.S. waters off the coast of California north of Point Conception ($34°27'N$) using data through 2020. Genetic evidence suggests overlapping distributions for the two species, with the majority of the sunset rockfish population occupying waters south of Point Conception. Alternative spatial structures for the vermilion rockfish assessment should be considered if additional data on stock structure and the distribution of the two species become available.

Catches

Over the past decade, vermilion rockfish in the assessed area off the coast of California in have been primarily caught by the recreational fishery (Table i). Annual total mortality of catch and discards of vermilion rockfish have ranged between 75-202 mt, with total mortality (catch + discards) in 2020 of 138 mt. Vermilion and sunset rockfishes landings from all sectors have historically been recorded as "vermilion rockfish" and sampling programs in California currently do not differentiate between the two species.

Recreational removals in California prior to 2004 were only estimated at large spatial scales (north and south of Point Conception) following the design of the Marine Recreational Fisheries Statistics Survey (MRFSS). Recent sampling (2004 – present) by the California Recreational Fisheries Survey (CRFS) produces estimates of vermilion landings and discard at a finer spatial resolution. Total removals north of Point Conception increased steadily following World War II, peaking in the late 1970s and 1980s with annual removals exceeding 363 mt per year (Figure i). Recent years have seen a steady increase in landings, with recreational fleets accounting for the majority of landings.

Table i: Recent mortality (mt) by fleet and total landings summed across all fleets in the model.

	Commercial			**Recreational**				
				Party/charter		Private/rental		
Year	Hook-and-line	Trawl	Net	Retained	Dead discards	Retained	Dead discards	Total Mortality
2011	10.047	0.000	0.000	40.278	0.293	49.362	0.145	100.124
2012	9.400	0.006	0.000	36.031	0.241	41.178	0.226	87.083
2013	13.845	0.005	0.000	21.101	0.121	40.642	0.123	75.837
2014	14.139	0.015	0.023	21.088	0.042	41.698	0.214	77.220
2015	18.172	0.410	0.010	40.022	0.109	64.580	0.226	123.528
2016	13.271	0.094	0.000	37.986	0.192	60.276	0.261	112.080
2017	14.226	0.062	0.002	92.320	0.384	58.287	0.279	165.560
2018	19.041	0.619	0.000	88.035	0.144	72.411	0.245	180.495
2019	19.593	0.039	0.000	91.995	0.310	91.878	0.630	204.445
2020	19.930	0.017	0.000	55.376	0.159	63.260	0.264	139.006

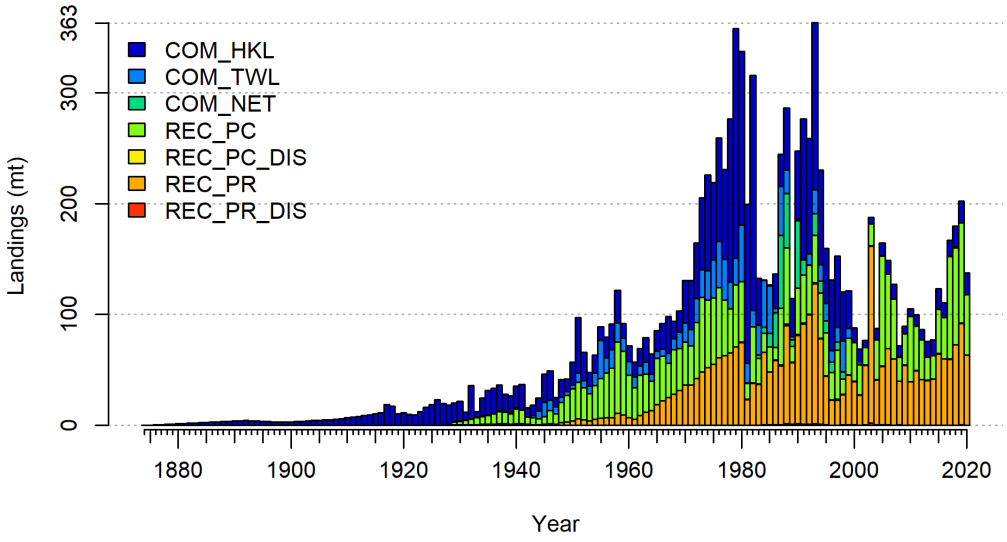

Figure i: Catch histories by fleet used in the base model (Commercial hook-and-line = COM_HKL, Commercial trawl = COM_TWL, Commercial net = COM_NET, Recreational party/charter retained = REC_PC, Recreational private/rental retained = REC_PR, Recreational party/charter dead discards = REC_PC_DIS, Recreational private/rental dead discards = REC_PR_DIS).

Data and Assessment

A full assessment was attempted in 2005, but not accepted for management and a data moderate assessment in 2013 was not reviewed. As such, this is the first benchmark assessment for vermilion and sunset rockfishes. The 2021 assessment uses Stock Synthesis 3 (version V3.30.17.0). The assessment is a two-sex model, with the population spanning from Point Conception ($34°27'N$) to the California/Oregon border ($42°00'N$). The assessment model operates on an annual time step covering the period 1875 to 2020 (not including forecast years) and assumes an unfished population prior to 1875. Population dynamics are modeled for ages 0 through 70, with age-70 being the accumulator age.

The model is conditioned on catch from two sectors (commercial and recreational) divided among seven fleets, and is informed by five abundance indices (one fishery-independent survey, two CPUE indices from shore-based recreational fishery sampling programs, and two CPUE indices from recreational onboard party/charter boat observer programs). The model is also fit to length composition data from fishery-independent and fishery-dependent sources, as well as age compositions conditioned on length. Discards for the commercial fleets are not included in the model. Commercial discards of vermilion are a small fraction of the total mortality and data on commercial discard length composition is limited. The recreational fishery is split into four fleets, one discard and one retained fish fleet each for the private/rental and the party/charter boat modes. The model also incorporates an updated length-weight relationship, length-based maturity schedule, and fecundity-at-length function.

The assessment estimates parameters for natural mortality of females and males, and sex-specific growth parameters. Year class strength is estimated as deviations from a Beverton-Holt stock-recruitment relationship beginning in 1970. Steepness of the Beverton-Holt stock-recruitment relationship is fixed at the mean of the prior, 0.72.

Stock Biomass

Spawning output of vermilion rockfish was estimated to be 1145 million eggs in 2021 (95% asymptotic interval: 915 - 1376 million eggs) or 43% (95% asymptotic interval: 25% - 61% million eggs) of unfished spawning output ("depletion," Table ii). Depletion is a ratio of the estimated spawning output in a particular year relative to estimated unfished, equilibrium spawning output.

In northern California, spawning output declined rapidly in the 1970s and early 1980s, likely falling below the minimum stock size threshold for a number of years in the 1990s and early 2000s, followed by a steady recovery since the late 2000s (Figures ii and iii). The spawning output in 2021 is just above the management target (40% of unfished spawning output).

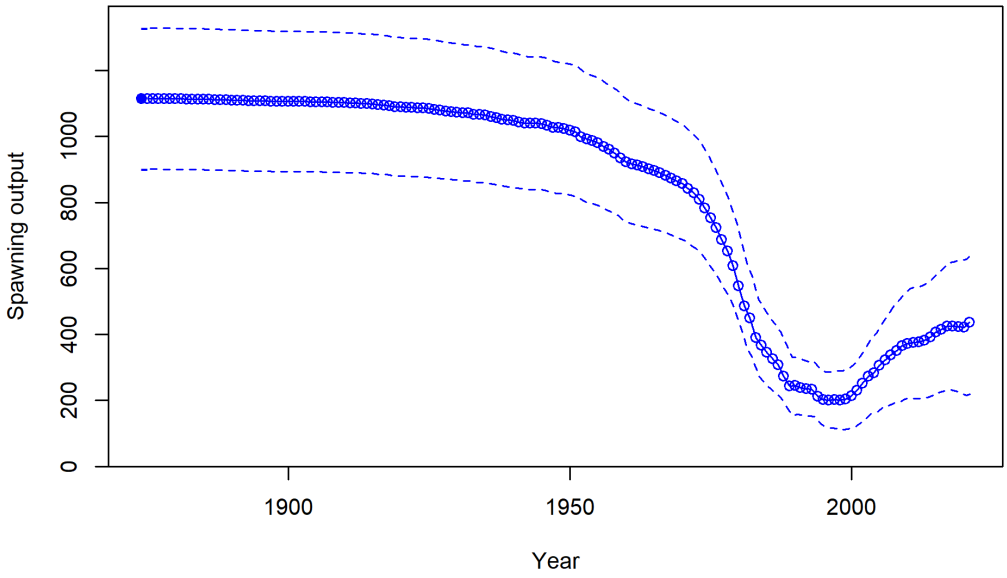

Figure ii: Estimated time series of spawning output (solid line with circles) with approximate 95% asymptotic confidence intervals (dashed lines).

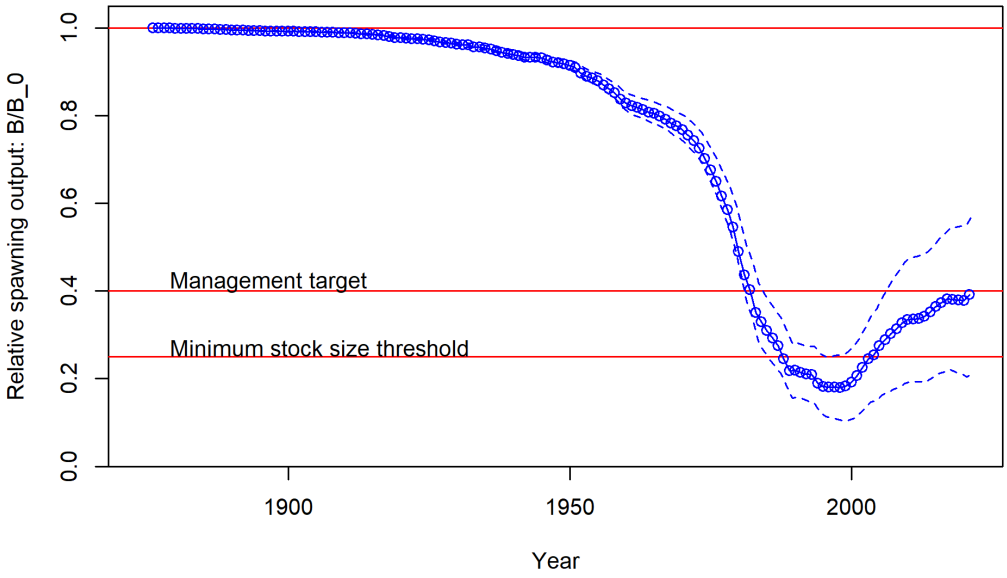

Figure iii: Estimated time series of spawning output relative to unfished spawning output (solid line with circles) with approximate 95% asymptotic confidence intervals (dashed lines).

Table ii: Estimated recent trend in spawning output and the fraction unfished and the approximate 95% asymtotic confidence intervals.

	Spawning Output			**Fraction Unfished**		
Year	Estimate	Lower Interval	Upper Interval	Estimate	Lower Interval	Upper Interval
2011	431.973	244.002	619.944	0.377	0.227	0.527
2012	435.431	244.955	625.907	0.380	0.229	0.531
2013	442.395	249.226	635.564	0.386	0.234	0.539
2014	454.034	257.314	650.754	0.396	0.241	0.552
2015	469.146	267.897	670.395	0.410	0.251	0.568
2016	479.639	273.578	685.700	0.419	0.257	0.581
2017	490.602	279.902	701.302	0.428	0.263	0.594
2018	490.707	275.944	705.470	0.428	0.260	0.597
2019	487.751	269.376	706.126	0.426	0.254	0.598
2020	482.178	260.377	703.979	0.421	0.246	0.596
2021	489.439	263.228	715.650	0.427	0.249	0.606

Recruitment

Recruitment deviations were estimated from 1970-2020 with a recent, strong recruitment in 2016 that has contributed to the recent increase in vermilion biomass in northern California (Table iii; Figure iv). The second highest estimated recruitment occurred in 1985 and is more certain than the estimated 2016 recruitment Overall, variability in recruitment is average (to low) in the years following 2016.

Table iii: Estimated recent trend in recruitment and recruitment deviations and the approximate 95% asymptotic confidence intervals.

	Recruitment			**Recruitment Deviations**		
Year	Estimate	Lower Interval	Upper Interval	Estimate	Lower Interval	Upper Interval
2011	225	116	437	-0.397	-0.956	0.163
2012	408	224	741	0.196	-0.279	0.672
2013	466	242	896	0.326	-0.220	0.872
2014	476	239	946	0.341	-0.248	0.930
2015	277	125	616	-0.215	-0.937	0.506
2016	1536	814	2901	1.472	0.963	1.980
2017	163	65	409	-0.800	-1.680	0.081
2018	387	147	1022	0.048	-0.892	0.988
2019	373	138	1004	0.003	-0.964	0.970
2020	374	138	1010	0.009	-0.961	0.978
2021	372	140	991	0.000	-0.980	0.980

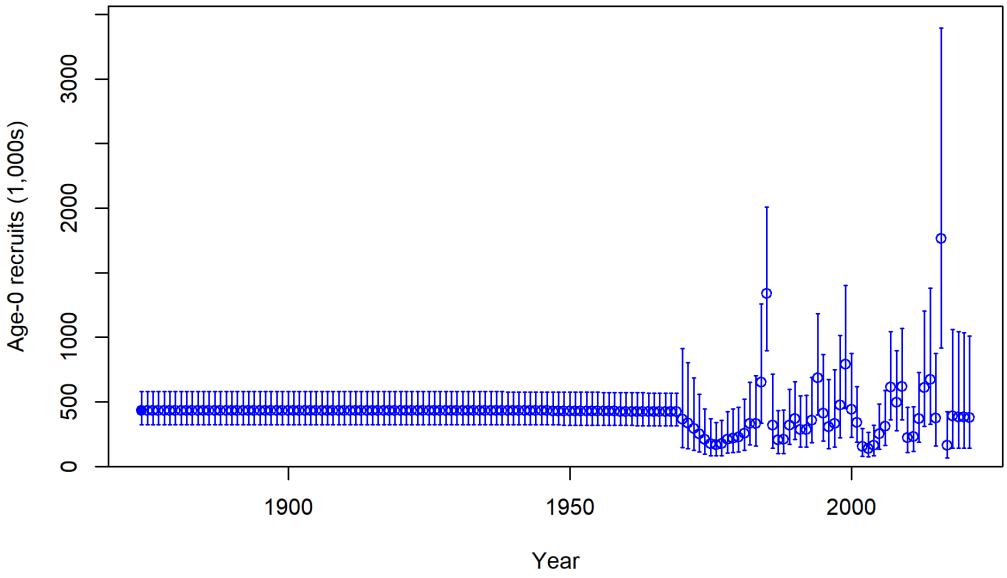

Figure iv: Age-0 recruits (1,000s) with approximate 95% asymptotic confidence intervals.

Exploitation Status

The annual (equilibrium) spawning potential ratio (SPR) for vermilion was above target from 2017-2019 (Table iv, Figure v). Prior to 2011, the fishing intensity exceeded the target for a number of years, regularly reaching levels 50% above target in the 1980s and 1990s (Figure v). As with current estimates of spawning output, recent estimates of exploitation status are highly uncertain, ranging from 68% to 129% of target in 2020 (Table iv). As a percentage of total biomass (ages 4+), California harvest rates peaked in the 1980s and 1990s, but have since declined to levels below 10% for the past decade (Figure vi). Harvest rates in northern California were near target in 2020, but above target in the three previous years, and the stock is just below the target biomass (Figure vii). However, the harvest rate in 2019 was above target, and may be more representative of future catches, all else equal, given reductions in fishing activity during the 2020 pandemic. The equilibrium yield curve is shifted left, as expected from the Beverton-Holt steepness parameter fixed at 0.72 (Figure viii).

Table iv: Estimated recent trend in the relative fishing intensity ($\frac{1-SPR}{1-SPR_{50\%}}$, where SPR is the spawning potential ratio) and the exploitation rate, with approximate 95% asymptotic confidence intervals.

	Relative Fishing Intensity			**Exploitation Rate**		
Year	Estimate	Lower Interval	Upper Interval	Estimate	Lower Interval	Upper Interval
2011	0.939	0.653	1.224	0.061	0.037	0.085
2012	0.826	0.558	1.094	0.051	0.031	0.071
2013	0.715	0.469	0.961	0.041	0.025	0.056
2014	0.701	0.461	0.941	0.040	0.024	0.055
2015	0.966	0.684	1.249	0.062	0.038	0.087
2016	0.905	0.629	1.181	0.058	0.035	0.080
2017	1.108	0.808	1.408	0.077	0.045	0.108
2018	1.164	0.861	1.467	0.081	0.047	0.115
2019	1.248	0.943	1.554	0.094	0.054	0.133
2020	0.990	0.684	1.296	0.061	0.035	0.088

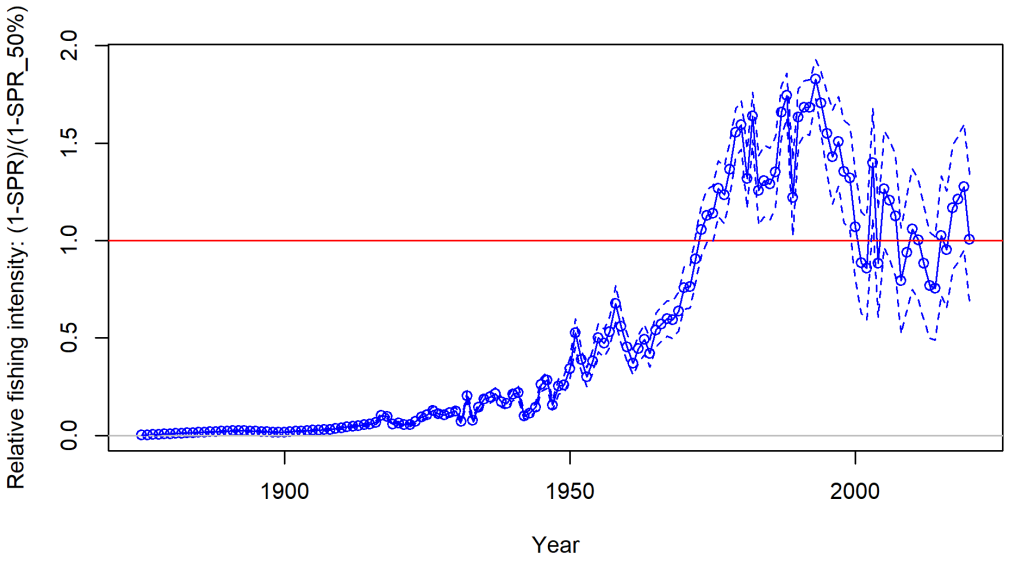

Figure v: Timeseries of relative fishing intensity ($\frac{1-SPR}{1-SPR_{50\%}}$ where SPR is the spawning potential ratio) with approximate 95% asymptotic confidence intervals (dashed lines).

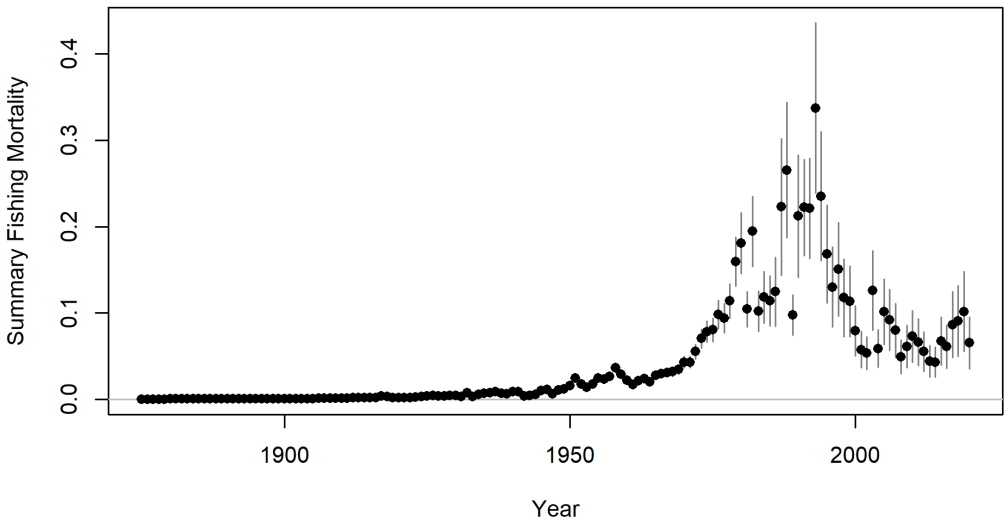

Figure vi: Time-series of estimated summary harvest rate (total catch divided by age-4 and older biomass) for the base case model with approximate 95% asymptotic confidence intervals (veritcal lines).

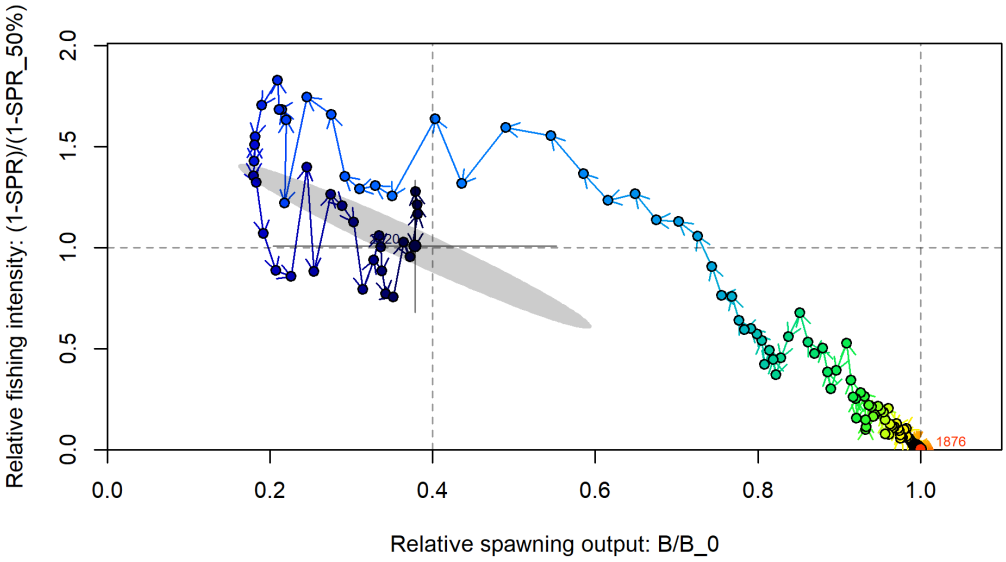

Figure vii: Phase plot of the relative biomass (also referred to as fraction unfished) versus the SPR ratio where each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show the 95% intervals based on the asymptotic uncertainty for each dimension. The shaded ellipse is a 95% region which accounts for the estimated correlations between the biomass ratio and SPR ratio. Fishing intensity in 2020 was reduced to due the pandemic.

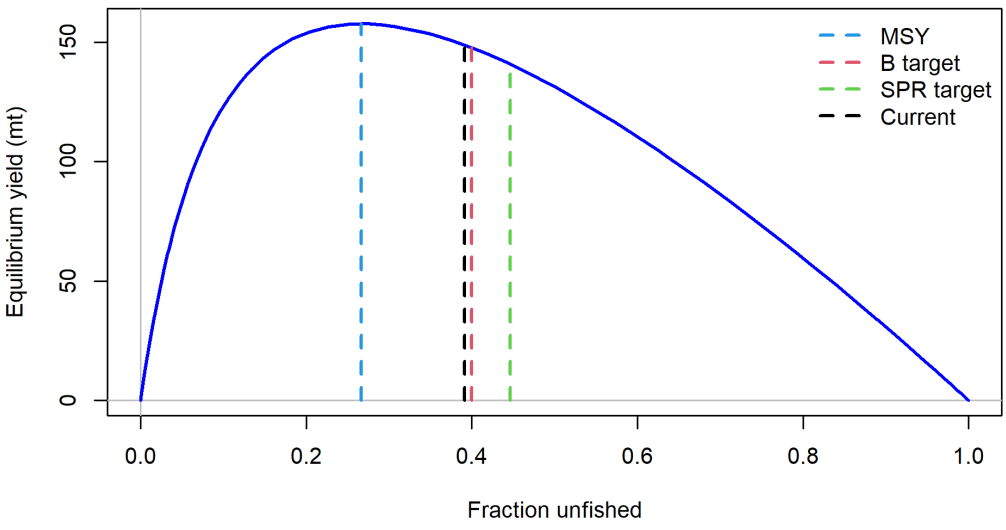

Figure viii: Equilibrium yield curve for the base case model with management quantities. Values are based on the 2020 fishery selectivities.

Ecosystem Considerations

In this assessment, ecosystem considerations were not explicitly included in analyses. This is primarily due to a lack of relevant data that could contribute ecosystem-related quantitative information for the assessment.

Vermilion/sunset rockfish are described as feeding on a wide range of both pelagic and benthic prey items, including forage fish species such as anchovies and mesopelagic fishes, squid, krill and octopus, as well as sporadically abundant pelagic organisms such as pyrosomes, salps and pelagic red crabs.

As with most other rockfish and groundfish in the California Current, recruitment, or cohort (year-class) strength appears to be highly variable for the vermilion/sunset rockfish complex, with only a modest apparent relationship to estimated levels of spawning output. Oceanographic and ecosystem factors are widely recognized to be key drivers of recruitment variability for most species of groundfish, as well as most elements of California Current food webs. Although it is feasible that ecosystem factors, the results of pre-recruit surveys for co-occurring species, or the results of other groundfish assessments might ultimately be used to forecast recruitment for more data-limited stocks such as vermilion/sunset. Such approaches would require more development and evaluation. Consequently, environmental factors are not explicitly considered in this assessment.

Reference Points

Reference point and management quantities for the vermilion rockfish base case model can be found in Table v. In 2021, spawning output relative to unfished spawning output ("depletion") is estimated at 43% (95% asymptotic interval: 25% - 61%). This stock assessment estimates that vermilion rockfish in the north is above the biomass target ($SB_{40\%}$), and well above the minimum stock size threshold ($SB_{25\%}$). Unfished age four-plus biomass is estimated to be 6342 mt in the base case model (95% asymptotic interval: 5667 - 7017 mt). The target spawning output ($SB_{40\%}$) is 458 million eggs (95% asymptotic interval: 366 - 550 million eggs), which corresponds with an equilibrium yield of 146 mt (95% asymptotic interval: 123 - 168 mt). Equilibrium yield at the proxy F_{MSY} harvest rate corresponding to $SPR_{50\%}$ is 139 mt (95% asymptotic interval: 118 - 160 mt), Table v and Figure viii).

Table v: Summary of reference points and management quantities including estimates of the approximate 95% asymtotic confidence intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output	1145.180	914.835	1375.525
Unfished Age 4+ Biomass (mt)	6341.790	5666.596	7016.984
Unfished Recruitment (R_0)	420.186	299.040	541.332
Spawning Output (2021)	489.439	263.228	715.650
Fraction Unfished (2021)	0.427	0.249	0.606
Reference Points Based on $SB_{40\%}$			
Proxy Spawning Output $SB_{40\%}$	458.073	365.935	550.211
SPR Resulting in $SB_{40\%}$	0.458	0.458	0.458
Exploitation Rate Resulting in $SB_{40\%}$	0.071	0.060	0.083
Yield with SPR Based On $SB_{40\%}$ (mt)	145.614	123.238	167.990
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output ($SPR_{50\%}$)	510.928	408.159	613.697
$SPR_{50\%}$	0.500		
Exploitation Rate Corresponding to $SPR_{50\%}$	0.062	0.052	0.073
Yield with $SPR_{50\%}$ at SB_{SPR} (mt)			
Reference Points Based on Estimated MSY Values			
Spawning Output at MSY (SB_{MSY})	308.931	249.480	368.382
SPR_{MSY}	0.341	0.332	0.349
Exploitation Rate Corresponding to SPR_{MSY}	0.104	0.087	0.121
MSY (mt)	155.029	130.706	179.352

Management Performance

Vermilion rockfish have been managed as part of the minor shelf rockfish complexes in the Pacific Coast Groundfish Fishery Management Plan. North $40^{\circ}10'N$ total mortality of the minor shelf rockfish complex has exceeded the OFL since 2011. South of $40^{\circ}10'N$, total mortality of the minor shelf rockfish complex has exceeded the OFL since 2015, and exceeded the ABC in most years since 2011 Total mortality estimates from the NWFSC are not yet available for 2019-2020. A summary of these values as well as other base case summary results can be found in Tables vi and vii.

Results from post-STAR base models in all areas (southern California, northern California, Oregon, and Washington) are presented in Table viii. The fraction of the northern CA model allocated to the northern management area (north of $40^{\circ}10'N$) is based on an Appendix in northern CA assessment.

Table vi: Summary of recent estimates and managment quantities for vermilion rockfish.

Quantity	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total catch (mt)	100.124	87.083	75.837	77.220	123.528	112.080	165.560	180.495	204.445	139.006	
$(1-SPR)/(1-SPR_{50\%})$	0.939	0.826	0.715	0.701	0.966	0.905	1.108	1.164	1.248	0.990	
Annual F	0.061	0.051	0.041	0.040	0.062	0.058	0.077	0.081	0.094	0.061	
Age 4+ Biomass (mt)	2741.110	2813.220	2961.290	3037.340	3087.710	3118.040	3173.250	3184.580	3135.420	3393.480	6335.880
Spawning Output (10^6)											
Estimate	431.973	435.431	442.395	454.034	469.146	479.639	490.602	490.707	487.751	482.178	489.439
Lower Interval	244.002	244.955	249.226	257.314	267.897	273.578	279.902	275.944	269.376	260.377	263.228
Upper Interval	619.944	625.907	635.564	650.754	670.395	685.700	701.302	705.470	706.126	703.979	715.650
Recruits (1,000s)											
Estimate	224.973	407.824	465.847	475.537	277.184	1536.160	162.592	387.483	372.609	373.837	371.777
Lower Interval	115.906	224.497	242.276	238.986	124.805	813.510	64.605	146.879	138.265	138.332	139.533
Upper Interval	436.670	740.858	895.729	946.231	615.609	2900.748	409.194	1022.226	1004.144	1010.280	990.579
Fraction Unfished											
Estimate	0.377	0.380	0.386	0.396	0.410	0.419	0.428	0.428	0.426	0.421	0.427
Lower Interval	0.227	0.229	0.234	0.241	0.251	0.257	0.263	0.260	0.254	0.246	0.249
Upper Interval	0.527	0.531	0.539	0.552	0.568	0.581	0.594	0.597	0.598	0.596	0.606

Table vii: Annual estimates of total mortality, overfishing limit (OFL), acceptable biological catch (ABC), annual catch limit (ACL) for vermilion in the minor shelf rockfish complex as reported in the GEMM report (NWFSC).

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
North of 40°10' N												
OFL	11.127	11.127	9.717	9.717	9.717	9.717	9.720	9.720	9.720	9.720	9.700	9.700
ABC	5.564	5.564	8.104	8.104	8.104	8.104	8.104	8.104	8.104	8.104	7.547	7.547
Total landings	15.249	18.695	14.149	10.504	13.472	12.104	20.602	22.949	25.696			
CA rec landings	4.209	4.867	2.657	2.950	5.018	4.549	6.490	7.631	7.884			
OR rec landings	6.102	9.150	6.305	3.949	4.653	3.689	8.798	9.199	9.252			
WA rec landings	1.001	0.911	1.279	0.960	1.141	0.997	0.731	1.151	2.497			
Commercial landings	3.935	3.767	3.906	2.644	2.661	2.799	4.557	4.966	6.063			
Research	0.002		0.002	0.002		0.069	0.026	0.002				
South of 40°10' N												
OFL	308.359	308.359	269.276	269.276	269.276	269.276	269.280	269.280	269.280	269.280	269.280	269.280
ABC	154.179	154.179	224.576	224.576	224.576	224.576	224.580	224.580	224.580	224.580	209.515	209.515
Total landings	210.310	235.216	237.074	197.043	334.984	292.375	341.207	344.454	484.967			
CA rec landings	191.437	216.480	208.198	167.572	291.779	260.162	287.493	278.158	413.946			
Commercial landings	16.928	16.642	26.601	26.607	39.669	29.148	48.195	59.644	67.189			
Research	1.944	2.094	2.275	2.863	3.536	3.065	5.519	6.652	3.832			

Table viii: Combined reference points for the four stock assessments conducted for vermilion and sunset rockfishes in 2021. The fraction of the northern California stock that is estimated to be north of $40^\circ 10' N$ is 4.44% (see the appendix in the northern CA model for more details). The projected OFLs (2023-2032) assume full attainment of GMT-projected catches for 2021-22, and catches based on the PFMC harvest control rule given $p* = 0.45$ and $\sigma = 1$.

Description	CA South model	CA North model	$34^\circ 27' N$ to $40^\circ 10' N$	South of $40^\circ 10' N$	$40^\circ 10' N$ to CA/OR border	OR model	WA model	North of $40^\circ 10' N$
Unfished spawning output (10^6 eggs)	977.8	1145.2	1094.8	2072.6	50.4	29.2	2.8	82.4
Total Biomass, mt	6263.3	6458.0	6173.8	12437.1	284.1	439.4	36.6	760.2
Unfished Recruitment (1000s of fish)	809.3	420.2	401.7	1211.0	18.5	16.3	2.5	37.3
Spawning Output (2021, 10^6 eggs)	471.2	489.4	467.9	939.1	21.5	21.4	1.5	44.4
Fraction Unfished (2021)	0.5	0.4				0.7	0.6	
Reference Points Based on $SPR_{50\%}$								
Proxy Spawning Output (10^6 eggs)	439.0	510.9	488.4	927.5	22.5	13.0	1.2	36.7
Proxy MSY, mt	148.3	139.0	132.9	281.2	6.1	7.9	0.8	14.8
GMT Projected Catch, 2021, mt	210.3	226.8	216.8	427.1	10.0	13.0	2.7	25.6
GMT Projected Catch, 2022, mt	210.3	226.8	216.8	427.1	10.0	13.0	3.3	26.2
OFL 2023, mt	159.4	154.2	147.4	306.8	6.8	13.5	0.7	21.0
OFL 2024, mt	158.8	157.8	150.9	309.7	6.9	13.4	0.7	21.0
OFL 2025, mt	158.8	159.5	152.5	311.3	7.0	13.2	0.7	20.9
OFL 2026, mt	159.0	159.9	152.8	311.8	7.0	12.9	0.7	20.6
OFL 2027, mt	159.3	159.4	152.4	311.7	7.0	12.6	0.7	20.3
OFL 2028, mt	159.6	158.7	151.7	311.3	7.0	12.3	0.7	20.0
OFL 2029, mt	159.9	157.8	150.8	310.7	6.9	12.0	0.7	19.7
OFL 2030, mt	160.3	157.0	150.1	310.3	6.9	11.8	0.8	19.4
OFL 2031, mt	160.6	156.3	149.5	310.1	6.9	11.5	0.8	19.2
OFL 2032, mt	161.1	155.9	149.0	310.1	6.9	11.3	0.8	18.9

Unresolved Problems and Major Uncertainties

The stratification of assessment areas was based on consideration of population structure identified in genetic analyses, differences in historical exploitation, differences in length composition within fleets, and availability of data sources. The Panel discussed the potential for alternative stratifications such as north and south of Cape Mendocino depending on the results of future analysis of population structure under the Saltonstall/Kennedy grant.

Natural mortality remains the primary axis of uncertainty across assessment areas. Additional collection of otoliths from across the range of the stock and continued ageing of available otoliths may help reduce uncertainty in the future. In the relatively data-rich southern model, steepness was estimated and uncertainties in both natural mortality and steepness were considered when determining alternative states of nature.

Decision Table and Forecasts

The forecasts of stock abundance and yield were developed using the post-STAR base model, with the forecast projections presented in Table ix. The total catches in 2021 and 2022 are set to the projected catch from the California Department of Fish and Wildlife (CDFW) by sector and model region, i.e., allocated north and south of $34^\circ 27' N$.

Uncertainty in the forecasts is based upon the three states of nature agreed upon at the STAR panel, reflecting three different natural mortality rates. The steepness parameter of the Beverton-Holt stock-recruit curve was fixed in the base model and in all of the forecasts. The northern California model is not data rich and while there is uncertainty in steepness, it was not well estimated in the base model when natural mortality was also estimated. The

alternative states of nature and the alternate states of nature maintain the female to male natural mortality rate ratio from the base model. To capture the 75% interval around the negative log-likelihood, alternate states were identified within 0.66 negative log-likelihood points from the base model where female $M = 0.0856$ and male $M = 0.0805$. The high state of nature fixes female $M = 0.0956$ and male $M = 0.08989$. For the low state of nature, female $M = 0.0769$ and male $M = 0.07231$.

For reference, the base model predicted $\sigma = 0.246$. The buffers between the OFL and ABC were calculated assuming a category 2 stock, with $\sigma = 1.0$ and a $p^* = 0.45$. Alternative catch streams (rows in the table) include $\sigma = 1.0$ with a $p^* = 0.4$, and removals of long-term equilibrium catch with and without a buffer assuming $\sigma = 1.0$ with a $p^* = 0.45$. The buffer multiplier with $p^* = 0.45$ ranges from 0.874 in 2023 ramping to 0.803 in 2032.

Current forecasts based on the alternative states of nature and requested catch streams project that the stock will remain above the target threshold of 40% in 2032 (Table x). In all of the scenarios of the low state of nature,
the stock remains below the target threshold of 40% until 2026 or 2027. The base model with the base catches results in an increasing stock over the period from 2023-2032. In all scenarios the catch significantly decreases from 2022 to 2023 in a all catch scenarios; assumed catch in 2022 is 227 mt, and 2023 catches from the base model range from 118-139 mt. The base model includes a portion of the stock within the northern management unit (north of $40°10'N$). An analysis based on the private/rental mode index through 2019 suggests that 4.44% of the catches from this model should be apportioned to the northern management unit for vermilion rockfish.

The STAT cautions that the GMT projections for catches in 2021-2022 (22 mt per year) exceed the maximum sustainable yield according to both proxies ($B_{40\%}$ and $SPR_{50\%}$) as well as the MSY value based on the estimated value of steepness (Table v). The northern California stock is just above target biomass in 2021 (43% of unfished spawning ouptut), so these catch levels are unlikely to result in significant stock declines over a short period of time. However, similar catch levels would exceed the overfishing limits (OFL) if carried forward for 2023 and beyond (viii), and would be unsustainable in the long term. Given recent and projected near-term exploitation levels, and especially if vermilion and sunset rockfishes continue to be managed as part of the minor shelf rockfish complex, the STAT recommends regular monitoring of total mortality for these two species to avoid excessive stock depletion and potential loss of yield.

Table ix: Projections of potential OFLs (mt), ABCs (mt), estimated age 4+ biomass (mt), estimated spawning output (10^6 eggs) and fraction unfished.

Year	Predicted OFL	ABC Catch	Age 4+ Biomass	Spawning Output	Fraction Unfished
2021	148.994	148.994	3459.01	489.439	0.427389
2022	156.383	156.383	3539.37	501.884	0.438257
2023	161.401	141.065	3590.72	518.613	0.452865
2024	164.761	142.519	3638.45	538.451	0.470188
2025	166.078	142.328	3666.95	555.898	0.485423
2026	165.981	140.918	3681.40	569.855	0.497611
2027	165.064	138.819	3686.31	580.383	0.506804
2028	163.786	136.434	3685.38	587.989	0.513445
2029	162.453	134.186	3681.30	593.289	0.518074
2030	161.233	131.889	3675.80	596.847	0.521181
2031	160.217	129.775	3670.30	599.185	0.523222
2032	159.428	128.020	3665.54	600.698	0.524543

Table x: Decision table summarizing 12-year projections (2021 to 2032) for vermilion based on three alternative states of nature spanning quantiles of spawning output in 2021. Columns range over low, medium, and high state of nature, and rows range over different assumptions of total catch levels corresponding to the forecast catches from each state of nature. Catches in 2021 and 2022 are fixed at catches provided by the CDFW.

				Low Productivity		Base Model		High Productivity	
				Female M = 0.0769 Male M = 0.0723 NLL = 1031.34		Female M = 0.0856 Male M = 0.0805 NLL = 1032		Female M = 0.0956 Male M = 0.0899 NLL = 1031.34	
	Year	Buffer	Catch (mt)	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
$p^* = 0.45, \sigma = 1$	2021	1.000	227	437	0.362	489	0.427	554	0.506
	2022	1.000	227	435	0.361	491	0.429	558	0.510
	2023	0.874	135	438	0.363	497	0.434	568	0.519
	2024	0.865	136	453	0.376	516	0.451	591	0.540
	2025	0.857	137	467	0.387	533	0.466	612	0.559
	2026	0.849	136	477	0.396	547	0.478	629	0.575
	2027	0.841	134	485	0.402	558	0.487	642	0.587
	2028	0.833	132	491	0.407	566	0.494	652	0.595
	2029	0.826	130	496	0.411	572	0.500	658	0.602
	2030	0.818	128	499	0.414	577	0.504	663	0.606
	2031	0.810	127	502	0.416	580	0.507	666	0.608
	2032	0.803	125	505	0.418	583	0.509	667	0.610
$p^* = 0.40, \sigma = 1$	2021	1.000	227	437	0.362	489	0.427	554	0.506
	2022	1.000	227	435	0.361	491	0.429	558	0.510
	2023	0.762	118	438	0.363	497	0.434	568	0.519
	2024	0.747	118	456	0.378	519	0.453	593	0.542
	2025	0.733	118	472	0.392	539	0.470	616	0.563
	2026	0.719	117	487	0.404	556	0.485	636	0.581
	2027	0.706	115	499	0.414	570	0.498	652	0.595
	2028	0.693	113	509	0.422	581	0.508	664	0.607
	2029	0.680	111	518	0.429	591	0.516	674	0.615
	2030	0.667	108	525	0.436	599	0.523	681	0.622
	2031	0.654	106	533	0.442	606	0.529	686	0.627
	2032	0.642	105	539	0.447	612	0.534	691	0.631
Long-term Equil. Yield (MSY proxy, $SPR_{50\%}$), no buffer	2021	1.000	227	437	0.362	489	0.427	554	0.506
	2022	1.000	227	435	0.361	491	0.429	558	0.510
	2023	1.000	139	438	0.363	497	0.434	568	0.519
	2024	1.000	139	453	0.376	516	0.451	590	0.539
	2025	1.000	139	467	0.387	533	0.465	610	0.558
	2026	1.000	139	477	0.396	546	0.477	627	0.573
	2027	1.000	139	485	0.402	557	0.486	639	0.584
	2028	1.000	139	491	0.407	564	0.493	647	0.591
	2029	1.000	139	495	0.410	569	0.497	652	0.596
	2030	1.000	139	497	0.412	572	0.499	654	0.598
	2031	1.000	139	98	0.413	573	0.500	655	0.598
	2032	1.000	139	499	0.414	573	0.501	654	0.597
Long-term Equil. Yield (MSY proxy, $SPR_{50\%}$), with buffer	2021	1.000	227	437	0.362	489	0.427	554	0.506
	2022	1.000	227	435	0.361	491	0.429	558	0.510
	2023	0.874	122	438	0.363	497	0.434	568	0.519
	2024	0.865	120	456	0.378	518	0.453	593	0.542
	2025	0.857	119	472	0.392	538	0.470	616	0.563
	2026	0.849	118	486	0.403	555	0.485	635	0.580
	2027	0.841	117	498	0.413	569	0.497	651	0.595
	2028	0.833	116	508	0.421	580	0.507	663	0.606
	2029	0.826	116	516	0.428	589	0.515	672	0.614
	2030	0.818	115	522	0.433	596	0.521	678	0.620
	2031	0.810	114	528	0.438	602	0.526	682	0.624
	2032	0.803	113	533	0.442	606	0.529	685	0.626

Research and Data Needs

The following are high priority research and data needs for this assessment. Additional details for each topic can be found in the full assessment.

We recommend the following research be conducted before the next assessment:

- Develop a coastwide hook-and-line survey to provide indices of abundance and associated biological sampling providing representative data in untrawlable habitats.
- Examine the available tools more fully in cases when a survey's footprint is abruptly changed as a result of management action. These tools may include (but are not limited to), treating the "new" and "old" surveys as completely separate (aka breaking the survey), using selectivity blocks, or spatial/temporal modeling approaches. This avenue is important for many fishery-independent and -dependent indices, as they are subjected to numerous spatial management changes which in turn can affect the veracity of the data collected. Additional efforts are needed to investigate how fishery selectivity changes with management changes and how best to address the effects of management changes on length composition and indices.
- Expansion of the California Collaborative Fisheries Research Project from the current 120 ft depth or starting similar surveys that sample in deeper waters outside, if not inside MPAs and other closed areas to encompass the full depth distribution of vermilion and sunset rockfish or other shallow shelf rockfish species would provide valuable data for future assessments.
- Conduct additional investigations to resolve uncertainties in historical catch reconstructions would improve estimates of the scale of assessments and provide more representative removal estimates.
- Explore appropriate methods of including catches as numbers of fish vs. biomass.
- Connectedness of this stock with Southern California (below point Conception) is an unresolved uncertainty as outlined in the STAT report and elsewhere in this report. Further studies on larval/juvenile/adult movement via tagging or other methods are warranted. Additionally population substructure investigations, particularly north and south of Cape Mendocino are also recommended.
- Development of a more comprehensive fishery-independent index is a priority for this region. This could involve expansion of the CCFRP across depths and latitudes or expansion of the NWFSC hook-and-line survey northward.